DOES SOLAR RADIO EMISSION TRIGGER SKR ?

Michael D. Desch

Laboratory for Extraterrestrial Physics
NASA/Goddard Space Flight Center
Greenbelt, MD 20771, USA

Abstract

Using Voyager 1 data I have made a preliminary search for evidence of both triggering and enhancement of Saturn Kilometric Radiation (SKR) by solar Type III bursts. The interval from 1 September 1980 to 30 September 1980 was examined at a frequency near the spectral peak of the SKR (385 kHz). The investigation compared emission levels before and after the arrival of Type III bursts at Saturn by subjecting the data to both superposed epoch analysis and intensity distribution analysis. Strong SKR associated with the arrival of a high–density solar wind stream at Saturn was removed to avoid possible masking of a weak triggering effect. No evidence of triggering or of enhancement of SKR due to the arrival of Type III bursts at Saturn could be found. Suggestions are made for further study.

1. Introduction

Calvert (1981c), Farrell and Gurnett (1985) and Farrell et al. (1986) have demonstrated that some of the earth's auroral kilometric radiation (AKR) can be stimulated by solar radio bursts. Solar Type III bursts, the dominant solar emission at kilometer wavelengths, trigger the AKR by adding sufficient threshold wave energy to an existing oscillator which then grows in intensity via a feedback mechanism until the radio waves escape and are recognized as AKR (Calvert, 1982). The evidence for triggering at earth has raised the intriguing possibility that a similar mechanism might be operating at the other radio planets. A convincing demonstration of triggering at, say, Jupiter or Saturn, would provide strong evidence that radio lasing is a widespread phenomenon.

Studies of the Jovian hectometer wavelength emission (HOM) for evidence of triggering have led to a standoff, with Calvert (1985a,c) and Desch and Kaiser (1985) claiming positive and negative results, respectively. In the present paper, the evidence for triggering at Saturn is examined quantitatively, following approximately the fashion of Farrell and Gurnett (1985) and Farrell et al. (1986). Saturn presents us with an interesting analog to test because the SKR is more like AKR than either the Jovian or Uranian emissions. Like AKR, SKR is strongly modulated by the solar wind input (Gallagher and D'Angelo, 1981; Desch, 1982; Desch and Rucker, 1983), and exhibits little or no evidence of satellite modulation. The frequency range of the more intense SKR, approximately 80 to 500 kHz (Kaiser et al., 1981), is similar to the 50–500 kHz AKR range. Both SKR and AKR originate on field lines from a few tenths to about 3–4 planetary radii above the surface. Finally, both planets generate radio emission that occurs in strong bursts lasting a few hours, with intensities varying dramatically in both frequency and time.

2. Procedure

The analysis interval in this study extends from 1 Sept 1980 to 30 Sept 1980. This interval is ideal from the standpoint of the detectability of the SKR by Voyager 1; namely, the SKR is easily detectable by Voyager, but at the same time the SKR has not become so intense that the Type III bursts are no longer visible. The interval could be extended somewhat forward and backward in time, however, without significant loss of reliability. Thus far, only data at 385 kHz, that is near the emission spectral peak, have been examined. Figure 1 illustrates a typical radio spectrogram from the interval.

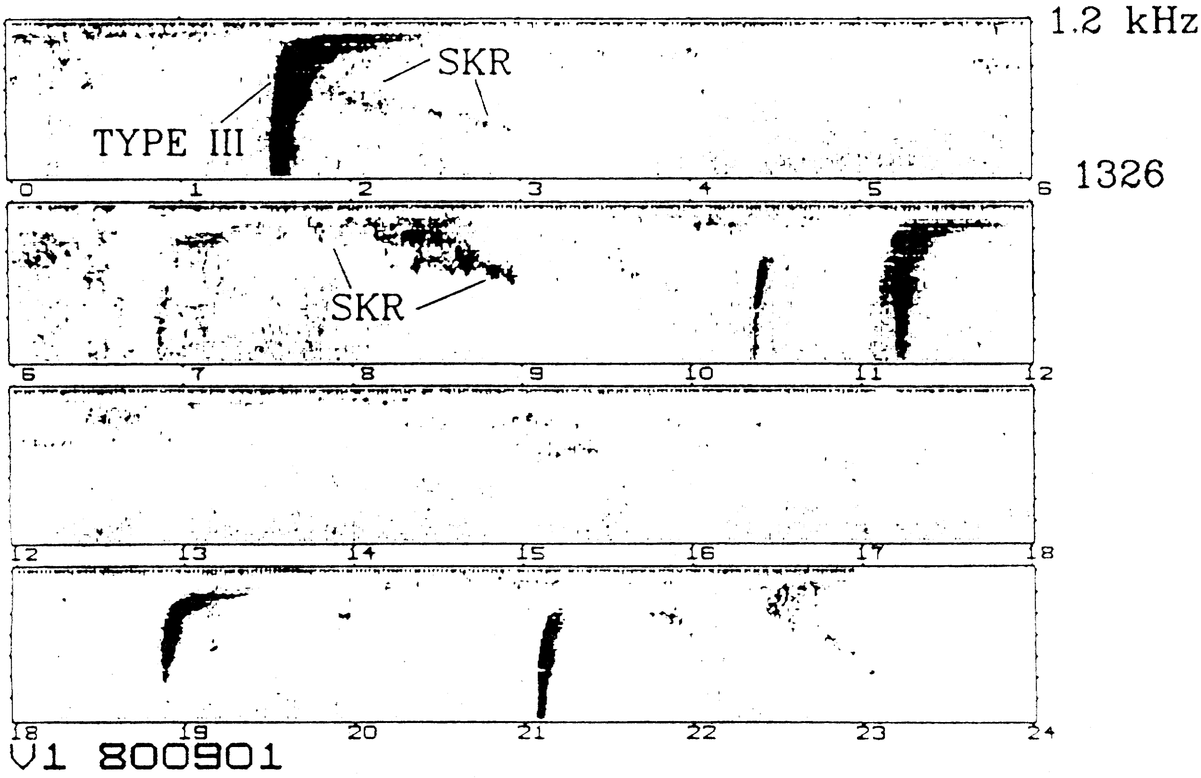

Fig. 1: An example of a radio spectrogram from the planetary radio astronomy instrument onboard Voyager 1. Four panels are shown, each covering 6 hours.

Five Type III bursts are visible and about four major episodes of SKR. One of the episodes, that near 02:00 hr, occurs in time coincidence with one of the solar bursts. However, a second, more intense episode of SKR near 08:00 hr does not occur in association with any Type III emission.

In order to quantitatively investigate the possibility that some of the SKR is triggered or enhanced by the arrival of the solar bursts at Saturn, we have first performed superposed epoch analyses on the data set. The procedure is illustrated in Figure 2. The start and stop time of each Type III was identified. All data for the hour preceding the *start* time of the Type III was stacked in bins, with each of the 75 bins representing a 48–sec average of the PRA data. The same procedure was used for the hour interval following the *stop* time of the Type III. The resultant midpoint of the superposition is referred to as the zero epoch. This procedure minimizes possible contributions from the Type III itself. If, however, SKR was visible superposed on top of the solar burst, then this emission was included in the stacking, provided the emission occurred after the round–trip light travel time between Voyager and Saturn (~8–10 min). Thus, although there is a tendency to systematically overestimate the intensity following the Type III, the effect is probably small and only affects a few bins. After all of the data were stacked, an average value for each bin was computed and plotted. Finally the mean value (y_1) of all the bins before zero epoch and the mean value (y_2) of all the bins after the zero epoch were computed.

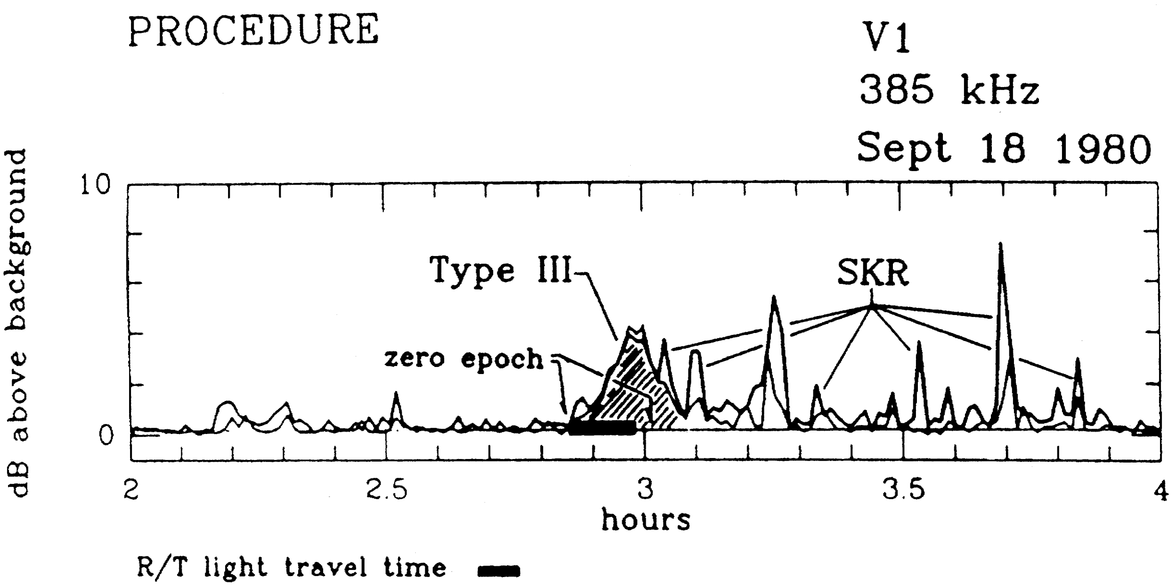

Fig. 2: This panel illustrates the procedure followed in tagging the zero epochs in preparation for the superposed epoch analysis. Here, a Type III burst is shown (shaded) at 385 kHz. Very weak SKR precedes the solar burst, while more intense SKR follows it.

Intuitively, if the difference between y_1 and y_2 is large, then the Type IIIs must be affecting the intensity level of the SKR in some way. But how large a difference constitutes a statistically significant change? We have assessed the statistical significance of the resultant difference by applying Student's t test as modified by Cochran. This follows the procedure of Farrell and Gurnett (1985). In addition we have used an interval estimator (e.g. Mendenhall, 1971) to compute the actual uncertainty in the difference between the means. We tested at the 95% confidence interval. If the uncertainty exceeds the difference, then no significance is attached to the difference. If the uncertainty is smaller than the difference, the result is considered significant.

By way of illustration, the results of the Farrell and Gurnett (1985) superposed epoch analysis on AKR is shown in Figure 3a. The lines drawn on either side of the zero epoch represent the mean values of the bins preceding and following the zero epoch. In the figure, the difference between the means and its uncertainty is shown. They are:

$$(2.01 \pm 1.92) \times 10^{-14}. \tag{1}$$

The first value, 2.01, is the difference between the means, $y_2 - y_1$, and the second value, 1.92, is the interval estimator Δy_{12} calculated as follows:

$$\Delta y_{12} = t_{\alpha/2} * [SDM_1{}^2 + SDM_2{}^2]^{1/2} \tag{2}$$

where:

$t_{\alpha/2}$ = Modified Student's t test statistic
SDM = standard deviation of the mean ($s/n^{1/2}$)
s = sample standard deviation for n (75) points.

Although the difference between the two means is slight, the uncertainty is smaller than the difference and it is considered that a significant change has occurred between the intensity level before and after the Type IIIs.

3. Superposed epoch analysis

The result of applying the superposed epoch technique to the analysis of the SKR is shown in Figure 3 (panels b–d). We use the same basic format as shown in Figure 3a, where now the log of the flux density is plotted as a function of the phase in minutes relative to the zero epoch. Approximately 40 Type III bursts occurred at 385 kHz during the entire 30–day analysis interval. The result of the first analysis is shown in Figure 3b. Here, all of the SKR data was considered. The difference between y_1 and y_2 was observed to be -1.6 (a slight decline after the zero epoch) with an uncertainty Δy_{12} of ± 2.3. Since the uncertainty is larger than the difference, we attach no significance to the observed change in intensity level.

There might be some concern that solar wind effects on the SKR, which are extremely strong, could easily mask any effect due to triggering. To illustrate this using the same format as above, we show the magnitude of the solar wind effect on the SKR that occurred during the period from 20 – 22 September when a very high density stream swept by Saturn and stimulated a major increase in SKR activity. The result is shown in Figure 3c. The zero epoch identified in this figure is the calculated arrival time of the high pressure stream at Saturn based on simple ballistic propagation from Voyager 1. Clearly a major increase in the mean flux level has occurred following, by about 10 hours, the arrival of the high–pressure stream. As shown in the figure, Δy_{12} is much smaller than the change in intensity levels, indicating a very significant result and thereby justifying our concern.

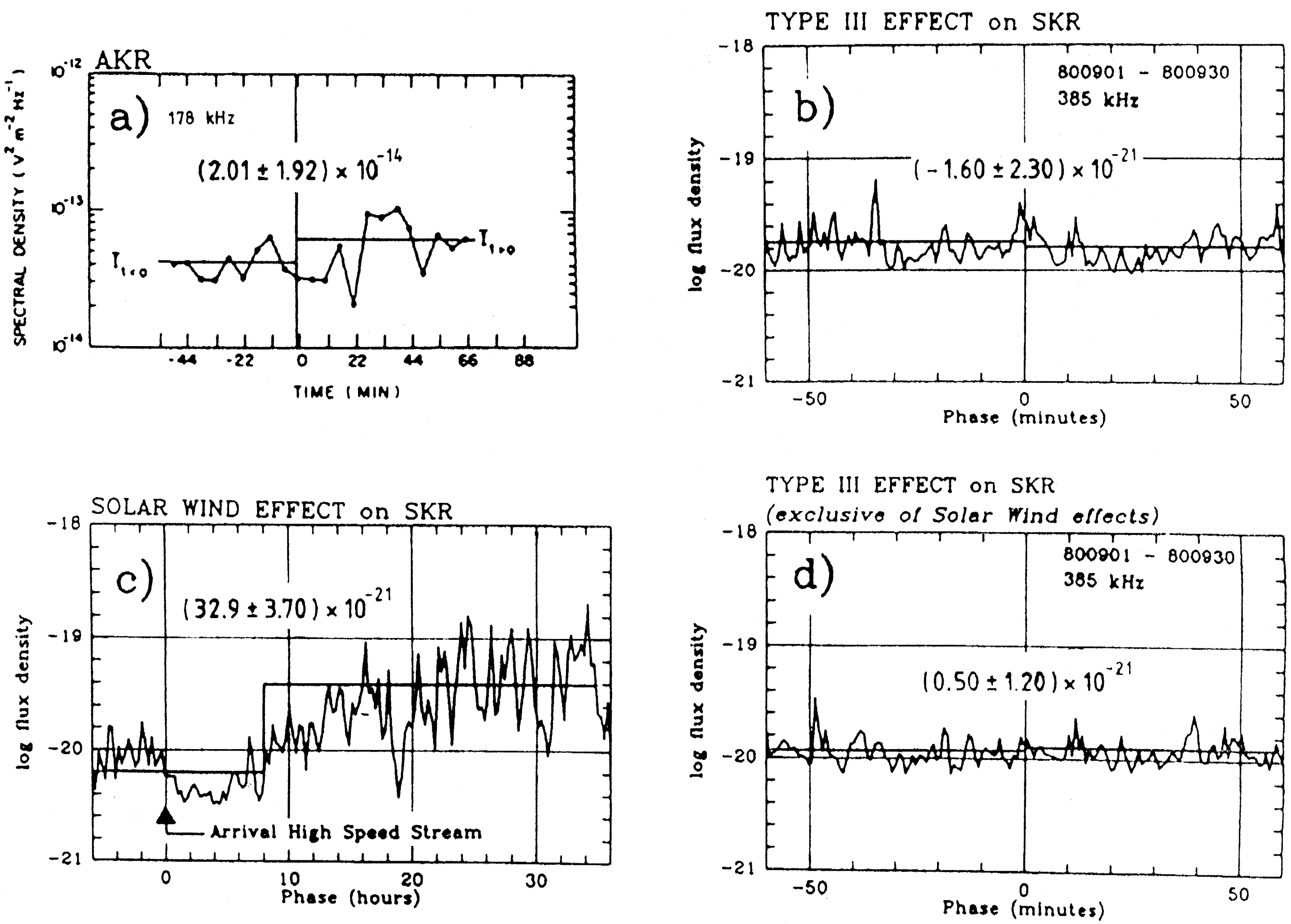

Fig. 3: (a) The results of a superposed epoch analysis performed by Farrell and Gurnett (1985) on AKR, with the statistical analysis as computed in text. (b) Results of superposed epoch analysis on all of the Saturn data in the analysis interval. (c) A superposed epoch analysis of the solar wind effect on SKR shows a highly significant difference between the pre and post epoch means, as should be expected. (d) Same as panel (b), but with strong solar-wind driven SKR removed. See Table 1 for summary of results.

In order to eliminate undue influence of the solar wind, the period from 20 through 22 September was eliminated from the study, and the analysis repeated, with the result shown in Figure 3d. Here a positive difference is found, with the mean value after zero epoch exceeding the value before zero epoch. However Δy_{12} is very much larger than the difference, namely 1.2 compared with 0.5, so the change is consistent with zero. No evidence of triggering is found, even after eliminating effects due to the solar wind. A summary of the statistical results using the superposed epoch analysis is shown in Table 1.

Table 1

Summary Superposed Epoch Results

Data Set	$y_2 - y_1$	$\pm$	Δy_{12}	Conclusion
SKR (all data)	-1.60	$\pm$	2.30	No triggering
SKR (high sw pressure)	32.9	$\pm$	3.70	Strong solar wind control
SKR (sw control removed)	0.50	$\pm$	1.20	No triggering

4. True triggering test

The results reported thus far actually constitute a search for either triggered or enhanced SKR following the arrival of a solar burst at Saturn. This is so because Saturn emission may be on going when the Type III is observed. In order to separate out the two effects, we have included only Type III bursts for which (a) no SKR was observed for about an hour before a given Type III, and compared the observed post- Type III increase with case (b) in which no emission was allowed after the Type III. The results are shown in Figure 4. The top panel illustrates case (a). A very significant increase is seen after the zero epoch. This should be expected, of course, even in the absence of a triggering effect because while no emission was allowed to occur before the Type IIIs, there was no restriction on what might occur after the Type IIIs. The converse case (b) is shown in the lower panel. As expected, the intensity level before the zero epoch is now elevated by a very significant amount. To test for triggering, case (a) post–epoch must be compared with case (b) pre–epoch. The result is that a slight decrease is seen; however, it is not statistically significant. Once again, no evidence of triggering is apparent.

Although we believe that this is a reliable way to go about testing for 'true triggering', the restriction that no emission occurs within one hour of the Type IIIs, reduces the size of the data set substantially. Only about 11–15 solar bursts were included in each survey, so that this analysis could probably benefit from an expanded analysis interval.

Farrell et al. (1986) performed an intensity distribution analysis on the AKR which appeared to be a more sensitive test of triggering. We have performed the same test on the SKR, using the same analysis interval and frequency as in the superposed epoch study. To demonstrate that triggering takes place by this technique, the overall intensity distribution of the emission that occurs after the Type IIIs must depart significantly from the intensity distribution of either the emission that precedes the Type III bursts or of some random sample. The intensity distribution is basically the number of events at a given flux level above the background noise.

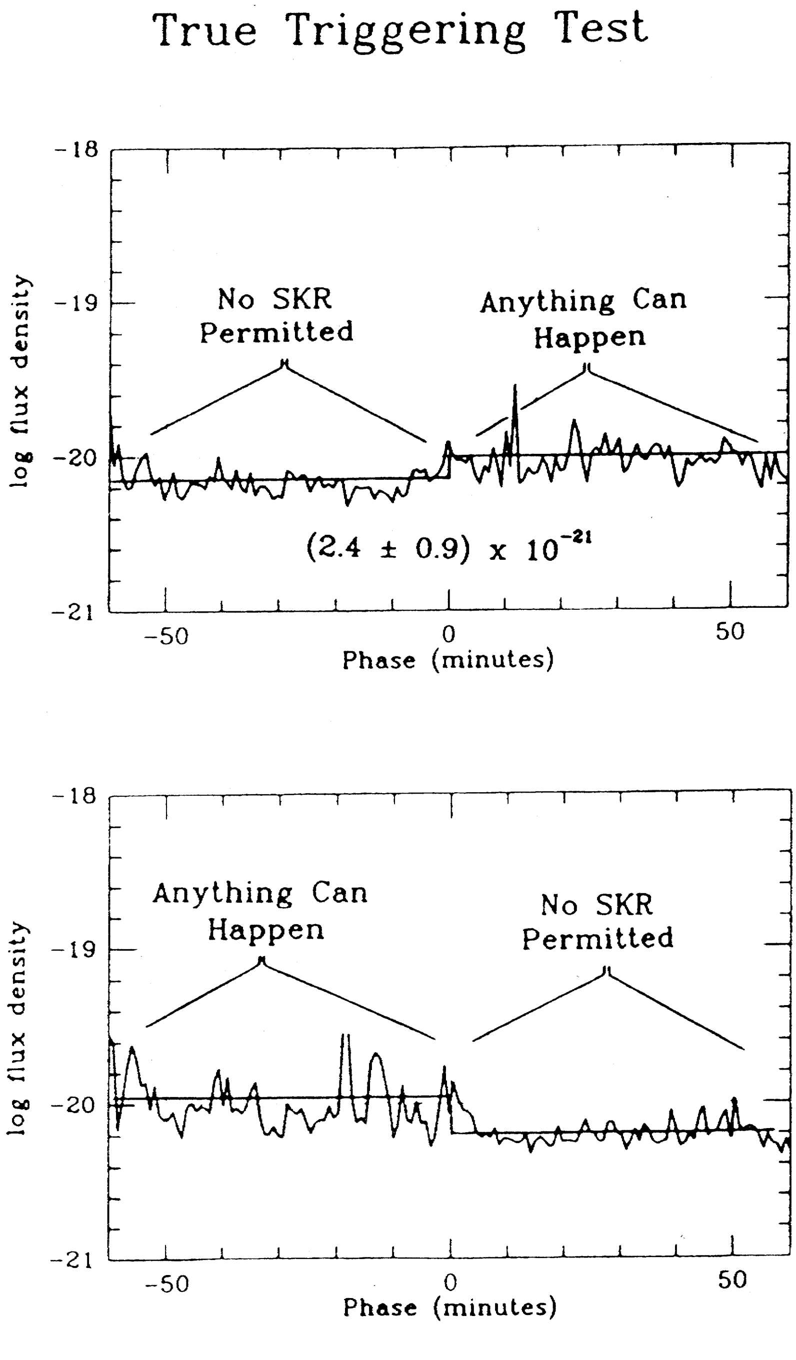

Fig. 4: Illustration of the superposed epoch analysis applied to a true triggering test. In the top panel, Type III bursts were selected which had no emission for 1 hour before the start of the Type III; no restrictions were placed on the hour following the Type III. As expected, a significant increase was observed following the Type III zero epoch. This result is compared in the bottom panel with the converse case, where no SKR is permitted in the hour following the Type IIIs, with no restrictions on the preceding hour. As is apparent, there is no significant difference between the mean post–epoch level in the top panel and the mean pre–epoch level in the bottom panel.

The result is shown in Figure 5, where we plot the integral percentage of events as a function of the observed flux level. The integral percent permits one to read off the percentage of events on the y–axis that equal or exceed a given intensity level (or in this case dB above background) on the x–axis. It is clear that there is no difference between the two curves; they are as close as they possibly can be without merging into a single line. By comparison the result of Farrell et al. (1986) for AKR is shown in the same figure. Here it is clear that the AKR behaves differently, with a preponderance of events following the Type IIIs having greater intensity levels.

Examined statistically, we can consider the pre–epoch distribution to represent an expected Poisson distribution of events. Then a Chi–squared analysis of the post–epoch distribution shows that it does not depart even remotely from what might be expected on the basis of chance occurrence alone. Specifically, given the value of Chi squared calculated and the number of degrees of freedom, we should expect the observed post–Type III SKR distribution to occur with about a 50% probability. By contrast, the AKR does manifest significantly different pre and post–epoch distributions.

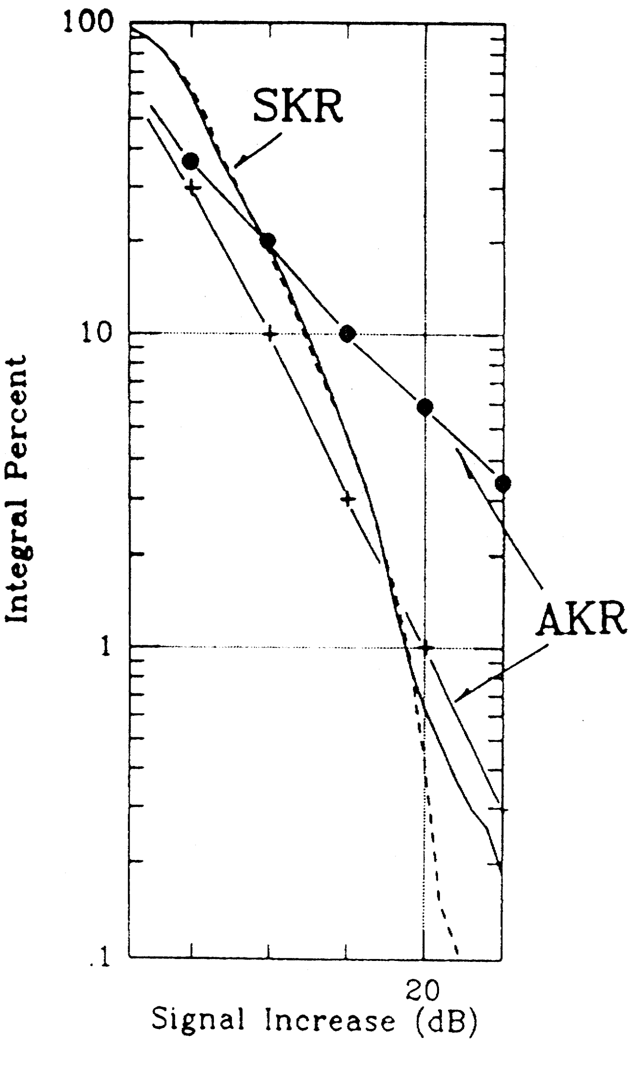

Fig. 5: Illustration of a comparison between the pre– and post–epoch intensity distributions for both SKR and AKR. For the SKR, there is no effective difference between the intensity of the SKR after Type III bursts (dashed line) compared with that before Type III bursts (solid line). The AKR pre–epoch curve is represented by the crosses and the post–epoch curve by the filled circles. Unlike the SKR curves, there is a significant difference between the pre– and post–epoch AKR curves (AKR result from Farrell et al., 1986).

5. Summary

In this preliminary study we have investigated the possibility that Type III solar bursts either trigger or enhance Saturn kilometer wave emission. The results have been negative. Neither superposed epoch nor intensity distribution analysis have provided any evidence for the type of triggering that apparently is associated with AKR. Although the study has been limited in some respects, we feel that the lack of even a strong hint of a positive result are adequate grounds to at least provisionally reject the hypothesis that triggering operates at Saturn.

To finalize this study, the following steps will be taken: (1) Voyager 2 data will be included, (2) The analysis interval will be extended, consistent with the requirement that the SKR be easily detectable without compromising the identification of the Type III bursts and (3) A Monte Carlo statistical analysis of the data will be performed to assess the applicability of Student's t test to data of this kind.

Acknowledgements: Throughout this study I have benefited immensely from discussions with Mike Kaiser, so much so that he has rudely insisted on becoming a co–author in any further studies.